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Coherent Instability Limits - Supplement

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Abstract

This note summarizes briefly various coherent instability limits for the bunch coalescing process in the proposed Main Injector. It also outlines possible intensity limits for the upgraded Tevatron with the electrostatic separators.

1. High Intensity Coalescing - Main Injector

One shall examine the longitudinal and transverse stability limits of a train of five consecutive, high intensity (8×10^{10} ppb), short proton bunches (ε = 0.5 eV-sec), injected from the Booster to the Main Injector (at the energy of 8.9 GeV), accelerated to the energy of 150 GeV, and then coalesced into a long bunch of the longitudinal emittance ε = 2.5 eV-sec. The transverse beam size is given by the normalized rms emittance of $\varepsilon = 4\,\pi$ mm mrad.

Guided by the previous study*, the lowest longitudinal threshold appears to be dominated by the microwave instability. Similarly, the transverse stability during the coalescing process seems to be limited by the growth rate of the coupled bunch resistive wall instability, while the single bunch stability is determined by the slow head-tail instability. Here, we will briefly summarize the upgrade limitations imposed by the above three instabilities.

♦ Resistive Wall Instability

During the coalescing process (at 150 GeV) a train of closely spaced bunches may exhibit an analog of a coupled bunch instability driven by the resistive wall impedance. Further analysis shows that indeed a rapidly growing envelope of the coherent betatron motion develops along the coalesced train of five bunches. Fig. 1 shows the characteristic growth-time of the instability as a function of the betatron tune. It implies that the bunch coalescing process is limited by the growth-time of of 30×10^{-3} sec, which may call for a damper.

♦ Slow Head-Tail Instability

Fig.2 illustrates growth-rate vs chromaticity plots for various modes, l, of the slow head-tail instability. The study was done at the injection energy (9.8 GeV), since the instability growth-rate is inversely proportional to energy. One can see (Table 1) that the two lowest modes are stable (l = 0, 1) and the most unstable mode (l = 3) is characterized by the growth-time $\tau^l = 5\times10^{-3}$ sec, which may also require

* Coherent Instability Limitations of pp and $p\bar{p}$ Upgrade Scenarios, S.A. Bogacz, FN-496, October 1988

an active damper. Values of critical chromaticities (where a given unstable mode reaches maximum of its growth-rate) are also listed in Table1.

♦ Microwave Instability

As one might expect, in the low energy region (8.9 GeV), the microwave instability is virtually dominated by the coherent space-charge force. The broad-band intensity threshold set by the impedance of the bellows is much higher than the one due to the coherent space-charge force, therefore the question of bellow shielding does not have any relevance here. Furthermore, one can see from Fig. 3, that this instability is quite safe for longer bunches of large transverse emittance. The lowest threshold appears to be way above 10^{12} ppb.

2. High Intensity Ramping - Tevatron

One should also examine another new scenario involving high intensity (3×10^{11} ppb), relatively long (ε = 0.5 eV-sec), proton bunches in the Tevatron (after a set of 24 new electrostatic separators have been installed). This last vacuum chamber structure seems to dominate the high frequency spectrum part of the Tevatron's transverse impedance (previously governed by the kicker magnets). The transverse beam size is given by the normalized rms emittance of $\varepsilon = 4\ \pi$ mm mrad.

Again, the lowest transverse threshold is set by the coherent betatron motion due to the higher modes of the slow head-tail instability. The summary of this limit is given below.

♦ Slow Head-Tail Instability

Similarly, Fig.4 illustrates growth-rate vs chromaticity plots for various modes, l, of the slow head-tail instability. The study was done at the injection energy (150 GeV), since the instability growth-rate is inversely proportional to energy. One can see (Table 1) that the lowest mode is stable ($l = 0$) and the most unstable mode ($l = 2$) is characterized by the growth-time $\tau^l = 10\times10^{-3}$ sec, which may also require an active damper. Again, the values of critical chromaticities are collected in Table1.

3. Summary

One can conclude that the bunch coalescing process in the Main Injector is limited by the coherent betatron motion: the resistive wall coupled bunch instability of the characteristic growth-time $\tau = 30\times10^{-3}$ sec and the single bunch slow head-tail instability with $\tau^l = 5\times10^{-3}$ sec. As far as the longitudinal thresholds are concerned, the lowest one, set by the microwave instability is way above the intensities of 10^{12} ppb.

Similar analysis done for the high intensity ramping in the Tevatron leads to a transverse constraint due to a fast growing slow head-tail instability with the characteristic growth-time $\tau^l = 10\times10^{-3}$ sec.

Apart from the active damper scheme one obvious way of suppressing particular modes of the slow head-tail instability is to avoid the critical chromaticities listed in Table 1.

ε [eV-sec.]	ν_β	l	ξ_{max}	τ^l [sec]
Tevatron (p-injection) @ 150 GeV, $N = 3\times10^{11}$ ppb				
2.5	19.456	0		stable mode
		1	3	33×10^{-3}
		2	5	10×10^{-3}
		3	25	13×10^{-3}
Main Injector (p-injection) @ 8.9 GeV, $N = 8\times10^{10}$ ppb				
0.5	22.6	0		stable mode
		1		stable mode
		2	7	33×10^{-3}
		3	12	5×10^{-3}

Table 1

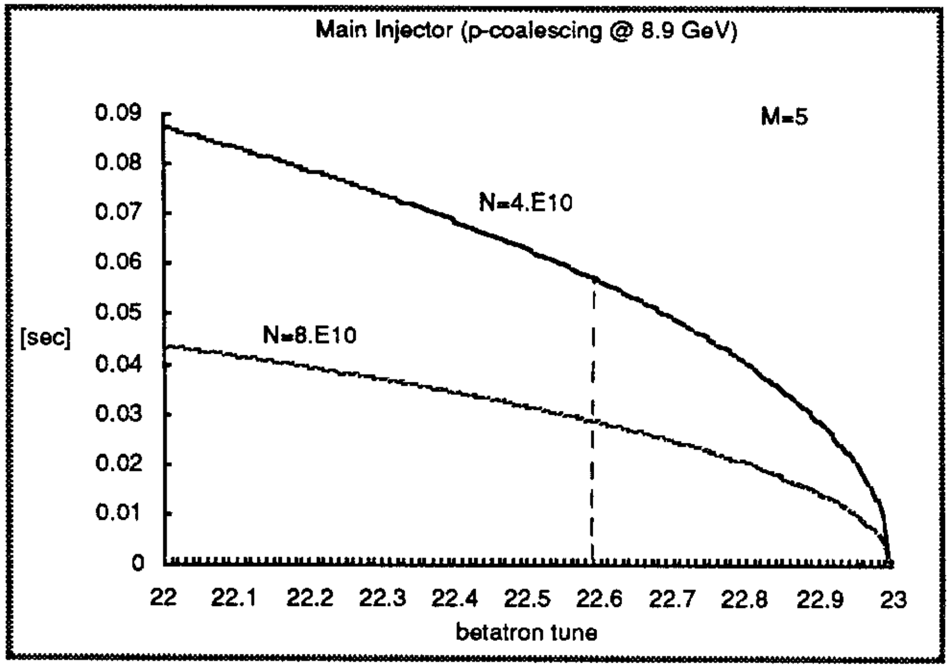

Main Injector (p-coalescing @ 8.9 GeV)
M=5
N=4.E10
N=8.E10
[sec]
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
22
22.1
22.2
22.3
22.4
22.5
22.6
22.7
22.8
22.9
23
betatron tune

Fig. 1

Main Injector (p-injection @ 8.9 GeV) N = 8.E10 ppb

ε = 0.5 eV-sec

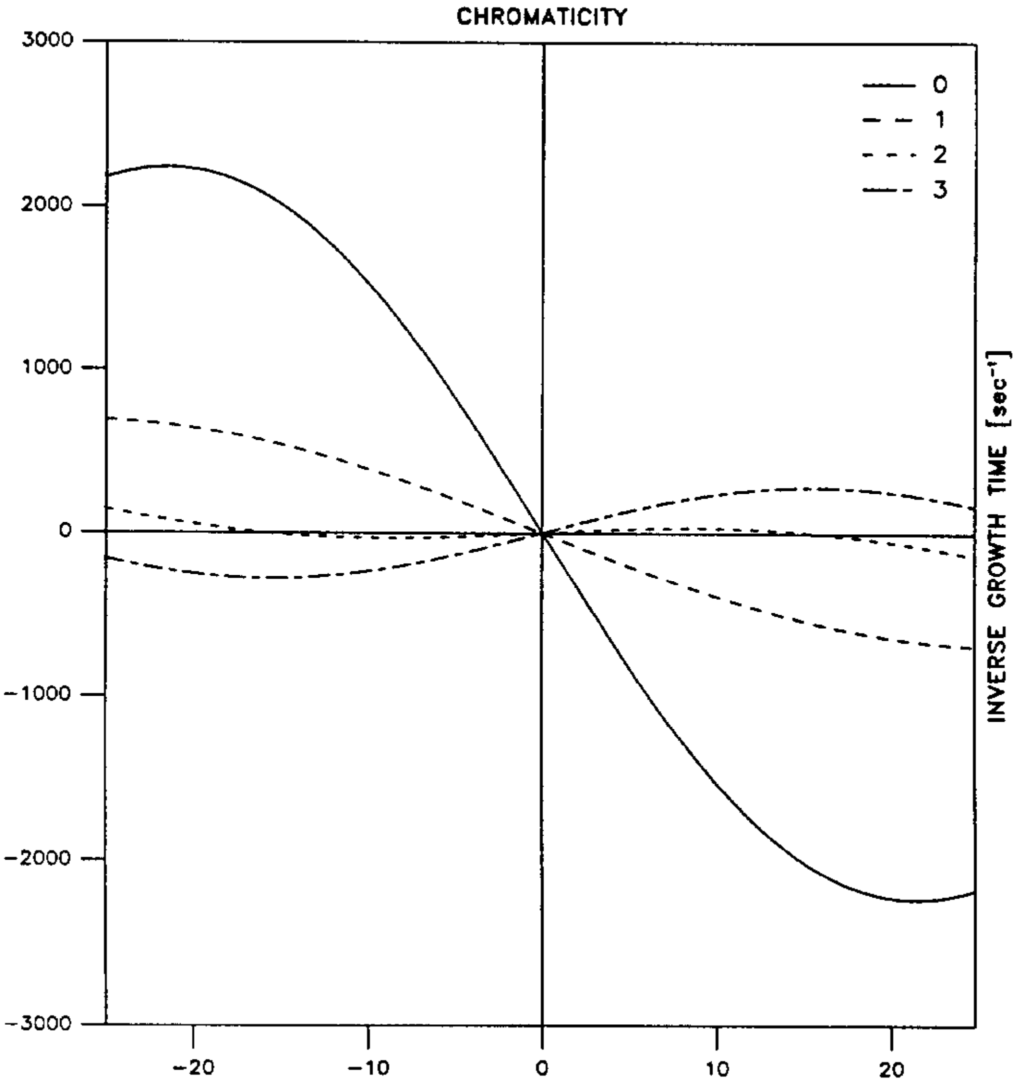
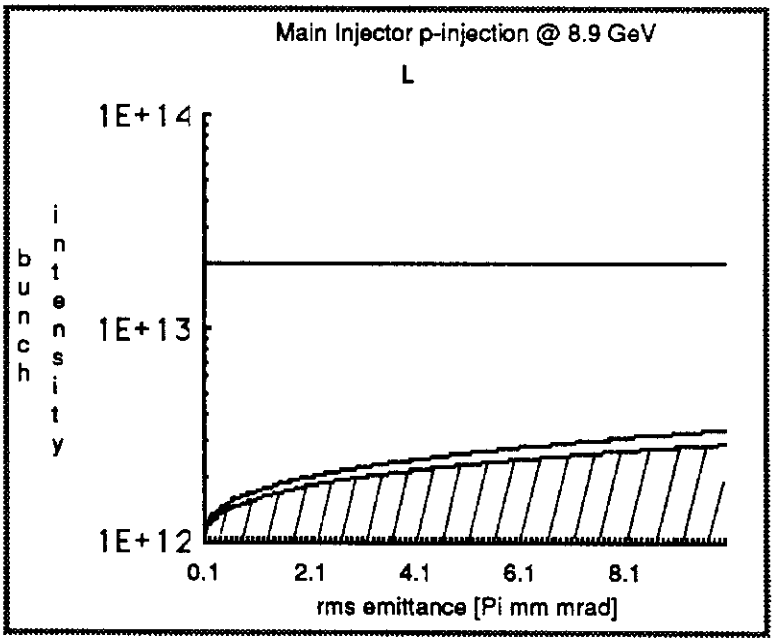


Fig. 2


Main Injector p-injection @ 8.9 GeV
L
1E+14
1E+13
1E+12
bunch intensity
0.1
2.1
4.1
6.1
8.1
rms emittance [Pi mm mrad]

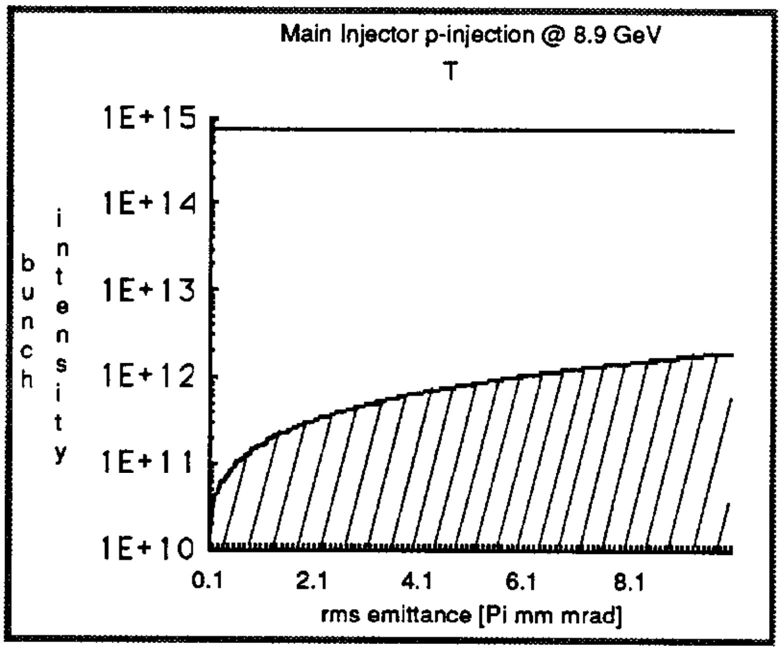

Main Injector p-injection @ 8.9 GeV
T
1E+15
1E+14
1E+13
1E+12
1E+11
1E+10
bunch intensity
0.1
2.1
4.1
6.1
8.1
rms emittance [Pi mm mrad]

Fig. 3

Tevatron (p-injection @ 150 GeV) N = 3.E11 ppb

ε = 2.5 eV-sec

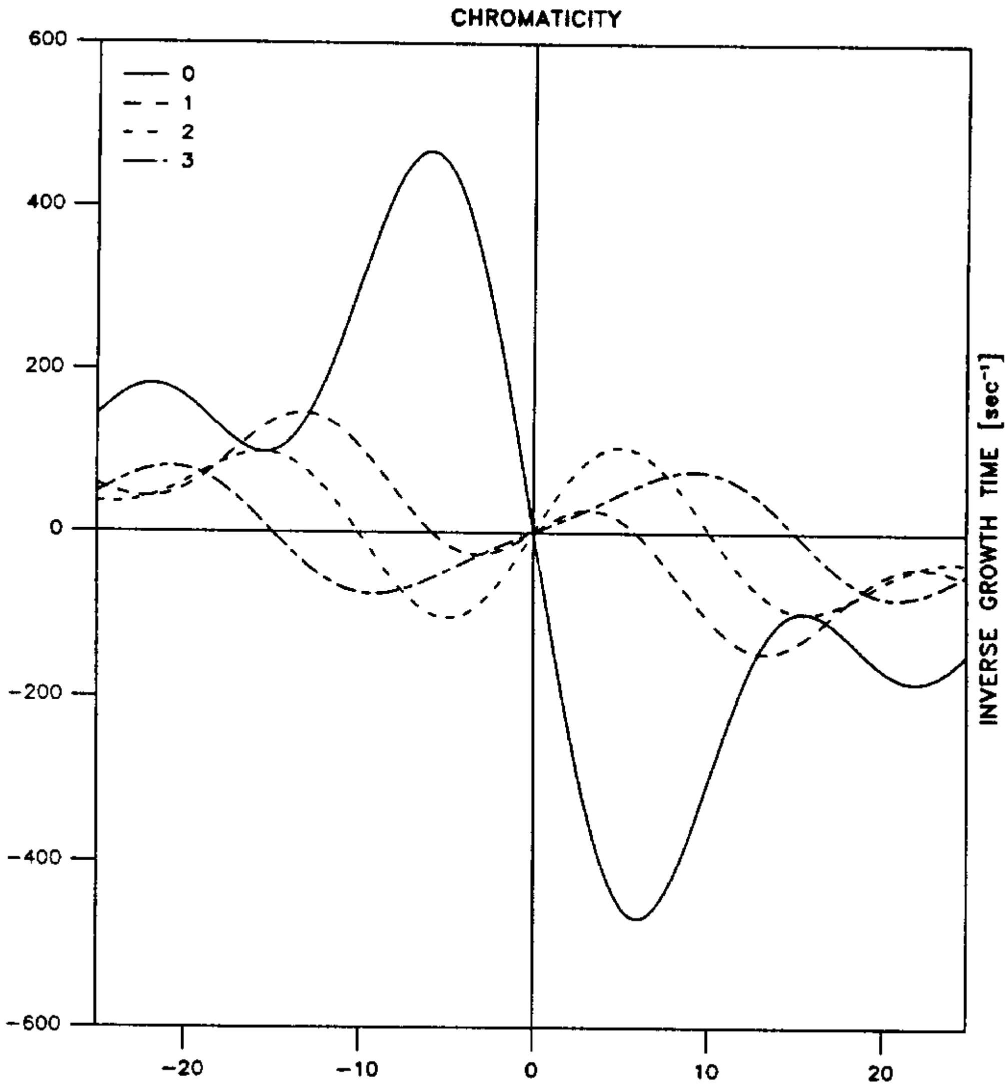


Fig. 4